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CONTINUOUS EXPLOSION-PUFFING OF POTATOES

ABSTRACT

Scientists at Eastern Regional Research Center have successfully continuously explosion-puffed potatoes for dehydration. By using a newly designed and fabricated puffing unit, they demonstrated that this equipment can be used in a continuous explosion puffing system (CEPS). Equipment development was carried out to effect commercial reliability, acceptable products and a high output rate. Potato dice, 1.0 cm (3/8 in.), at 27% moisture were processed in CEPS at a maximum rate of 454 kg/hr (1000 lb/hr). With mechanical refinements largely complete, an optimization study was made. Using product rehydration and flavor as criteria, a puffing pressure of 345 kilo pascals (50 psig) at a moisture content of about 26% was optimal for the 1.0 cm dice.

INTRODUCTION

FOOD PRESERVATION by dehydration yields substantial economies in transportation and storage (Duckworth, 1966) for perishable commodities. There has long been a need for a dehydration method suitable for large pieces of vegetables such as might be used in a dehydrated stew.

The explosion-puffing process (Cording and Eskew, 1962) developed at the Eastern Regional Research Center adds another dimension to dehydration. The process is unique in that it is applicable to fruits and vegetables in various piece forms and sizes. Its use allows large food pieces to be dried to lower moisture content; for example, a 1.90 cm (3/4 in.) potato cube can be dried to 7% moisture in 7 hr, whereas a cube of this size dried by conventional hot air drying requires 30 hr and dries to only 15%. Lesser time savings are realized on smaller dice (Sullivan et al., 1963; Cording et al., 1964).

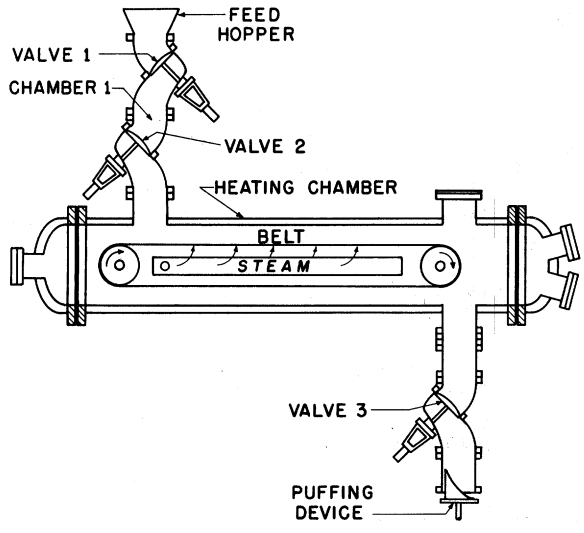

Fig. 1—Continuous explosion puffing system. Food pieces heated in a jacketed chamber are dropped from a belt into a discharge chamber (between valve #3 and the discharge device) from which they are explosively discharged.

Explosion-puffing of potatoes is carried out after potato pieces have been reduced to about 25% moisture by conventional hot air drying. During explosion-puffing at an elevated pressure and in a stream of superheated steam, the water within the partially dried pieces is rapidly brought to a temperature above its atmospheric boiling point. When the pieces are instantly brought to atmospheric pressure, a fraction of the water flashes into steam, creating the porous structure. After puffing, the potato pieces are dried by conventional means to 3–4% moisture.

Explosion-puffing was originally studied as a batch process (Sullivan et al., 1963; Cording et al., 1964). Rehydrated fruit and vegetable pieces made by this process compare well in color, flavor, and texture with freshly cooked counterparts. Potatoes prepared by the batch process exhibit good storage stability for up to a year (Sullivan et al., 1974). Although commercially feasible (Turkot et al., 1965; 1967), batch processing is relatively costly and labor intensive, encouraging a change to continuous operations. A continuous explosion puffing system (CEPS) was designed, fabricated, and is now under experimental study (Aceto, 1974).

To achieve continuous operation, the two major functions, heating and puffing, were separated (Cording, 1968). The food pieces are heated by superheated steam in a jacketed chamber (3.05m X 0.78m diam) (Fig. 1). These pieces are then dropped from a belt into a discharge chamber (between valve #3 and the discharge device). From here they are explosively discharged. This chamber's recovery time, for pressure and temperature, is short because of its small volume (about 0.068 m^3). This short recovery time gives better control of process variables.

EXPERIMENTAL

A TYPICAL COMMERCIAL potato processing variety, Maine Kennebec, cut into 1.0 cm (3/8 in.) dice was used in all experiments. All potato dice were given the same pretreatment (Cording et al., 1964) before processing in the CEPS. They were dried in either a tray dryer or a continuous belt dryer to predetermined moistures in the range of 20–35%.

Experiments were planned to determine (1) the feasibility of the design criterion of 454 kg/hr (1000 lb/hr) of partially dried potato dice and (2) optimal pressure, temperature and moisture levels in CEPS.

Capacity test

1725.2 kg of raw potatoes were processed and dried to 307.4 kg of 1 cm potato dice at 25% moisture which were processed through CEPS at the rate of 454 kg/hr (340 kg/hr dry basis). Internal CEPS conditions and moisture content of the dice for this CEPS test were determined from batch studies and preliminary continuous experiments (Table 1).

Optimization test #1

Raw potatoes were processed into partially dried 1 cm dice at five moisture contents differing by increments of 3–4% over a moisture range from 20–35%. CEPS was operated at four pressures 277, 345, 414 and 448 kiloPascals (kPa), or 40, 50, 60 and 65 psig, with the internal chamber temperature at 163°C. At each pressure, potato dice at five different moisture levels were processed through CEPS. For each condition, potato dice were fed at a rate of 163.5 kg/hr for 10 min. The explosion-puffed product was dried in a hot-air tray dryer at 66°C to 3–4% moisture.

Optimization test #2

In this test, moisture was held constant. Potato dice were processed

Table 1—CEPS conditions for 454 kg/hr[a]

Moisture, %	24.5
Internal temp, °C	176
Residence time, sec	84
Time on belt, sec	60
Discharge pressure, kPa[b]	414

[a] CEPS, continuous explosion puffing system
[b] kPa, kiloPascals

and dried to 25% moisture and studied at pressures of 345 and 414 kPa and at four internal temperatures 163, 168, 176 and 191°C. In this series, potato dice were also produced in the batch gun at 345 and 414 kPa as a control. Batch products were made with and without nitrogen injection (Cording and Sullivan, 1973). The CEPS study was made without nitrogen injection. As in the previous test, the explosion-puffed product was dried to 3–4% moisture.

Product evaluation

The rehydration characteristics of explosion-puffed potato dice were examined by two criteria: (1) the coefficient of rehydration (C_r) which measures the degree of rehydration referred to the original state (Eisenhardt et al., 1962) and (2) the analysis of headspace vapor by gas-liquid chromatography (GLC), which measures the concentration of flavor producing aldehydes.

For the rehydration studies, 25g of the explosion-puffed potato dice dried to 3–4% moisture were rehydrated by boiling 5 min in 150 ml of water. The water uptake of each sample was measured and then divided by its original raw weight to determine the coefficient of rehydration. The period of 5 min was selected as a conventional rehydration time.

Concentrations of 2-methylpropanal (2 MP) and 2- and 3-methylbutanal (2- and 3 MB) in the explosion-puffed potato dice were determined by GLC analysis of headspace vapor with ethyl butyrate as the peak area internal standard (Sapers et al., 1970). Increased levels of these compounds are indicative of the amount of Maillard browning and off-flavors related to browning. In explosion-puffing with steam only, conditions are normally favorable for the increased formation of these aldehydes (Cording and Sullivan, 1973).

RESULTS & DISCUSSIONS

WHEN THE CEPS capacity test was made, there was a moisture increase of 3.5% during puffing as found also during batch operation. The product puffed well and had excellent color. The dried dice rehydrated in 5 min.

The results of the first optimization study (Fig. 2) indicate that potato dice explosion-puffed at 414 kPa (60 psi) have a higher coefficient of rehydration than have samples processed at higher or lower pressures. The four curves shown were derived by curvilinear regression, $C_r = a_o + a_1(H_20) + a_2(H_20)^2$. The standard error of estimate, 4.05, was calculated from the pooled error variances. This showed that the curve at 414 kPa was significantly ($p = 0.05$) different from the other three. The optimum moisture for puffing appears to be between 22 and 28%. Potato dice above 28% moisture tend to clump together, nullifying the effect of explosion-puffing; this effect is observed in the downward slope of each curve. At 448 kPa (65 psi) the potato pieces failed to maintain their structure and disintegrated when puffed; this resulted in low coefficients of rehydration (Fig. 2). Regardless of their moisture level, potatoes puffed at 277 kPa (40 psi) still had hard centers after a 5-min boil. The optimum pressure, determined by coefficient of rehydration, is 414 kPa (60 psi).

The results of the second optimization study are shown in Tables 2 and 3. Table 2 compares the C_r and 2 MP and 2- and 3 MB values for batch operations, with and without nitrogen injection at 345 kPa (50 psi) and 414 kPa (60 psi). Statistical evaluation of the rehydration test resulted in confidence limits of ±1.9% ($p \leq 0.05$) for the coefficient of rehydration. Water uptake was greater at the higher pressures and when nitrogen was not used. It can be seen from Table 2 that the 2 MP and 2- and 3 MB values are also higher when nitrogen was not used. The samples for which nitrogen injection was used had no detectable off-flavors upon rehydration.

From this same lot of partially dried potatoes, tests were made in the CEPS. Table 3 compares the batch operation sam-

Table 2—Batch gun product data

Gas used	kPa[a]	C_r[b]	2 MP[c]	2- and 3 MB[d]
None	414	71	0.49	0.69
None	345	64	0.58	0.70
N_2	414	67	0.34	0.38
N_2	345	58	0.31	0.35

[a] kPa, kiloPascals
[b] C_r, coefficient of rehydration
[c] 2 MP, 2-methylpropanal
[d] 2- and 3 MB, 2- and 3-methylbutanal

Table 3—Comparison of batch with CEPS[a]

	345 kPa[b] (50 psi)				414 kPa[b] (60 psi)			
	Temp °C	C_r[c] %	2 MP[d]	2- and 3 MB[e]	Temp °C	C_r[c] %	2 MP[d]	2- and 3 MB[e]
Batch	–	58	0.30	0.35	–	67	0.33	0.38
	163	68	0.32	0.36	163	73	0.43	0.46
	168	76	0.37	0.45	168	80	0.51	0.67
CEPS	176	77	0.70	0.88	176	78	0.85	1.07
	191	75	0.76	0.95	191	82	0.96	1.26

[a] CEPS, continuous explosion puffing system
[b] kPa, kiloPascals
[c] C_r, coefficient of rehydration
[d] 2 MP, 2-methylpropanal
[e] 2- and 3 MB, 2- and 3-methylbutanal

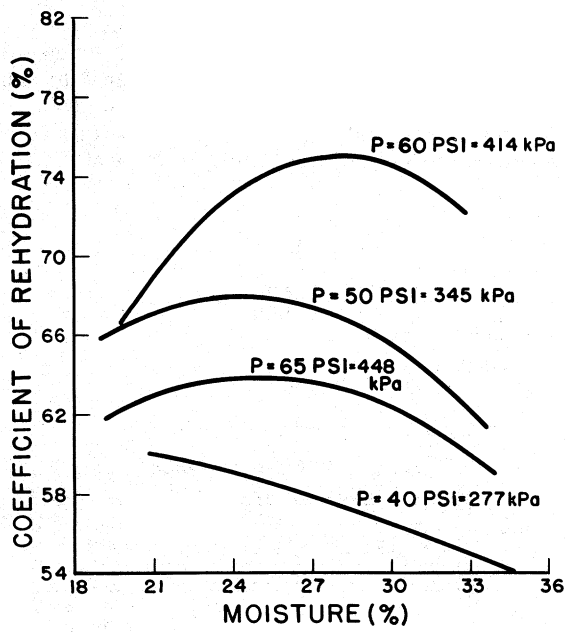

Fig. 2—Results of first optimization study show potato dice explosion-puffed at 414 kPa (60 psi) have a higher coefficient of rehydration than samples processed at higher or lower pressures.

ples made with nitrogen injection and samples made in the CEPS in which nitrogen was not used. The 2 MP and 2- and 3 MB values for the CEPS at 163 and 168°C and 345 kPa approach the 2 MP and 2- and 3 MP values of the batch operation; both of these samples from CEPS had no detectable off-flavor, whereas the other six did. The coefficients of rehydration of these samples are not as high as those at 414 kPa but are substantially higher than that of the potato dice made from the batch operation.

CONCLUSIONS

THE CAPACITY TEST established that the continuous explosion puffing system met the designed, practical rate. The system is flexible; for example by reducing puffing pressure from the optimal level determined, one could produce a slightly harder product without an equivalent degradation in flavor. The harder product may be more suitable for applications in which the reconstituted potatoes will be retorted. The CEPS does not require nitrogen injection for potato processing as the batch operation did. The elimination of the use of nitrogen lowers the cost of operation. Potatoes puffed better in the CEPS than in the batch operation, as determined by the coefficient of rehydration. From the standpoint of rehydration, potatoes puff best at 414 kPa (60 psi), but samples puffed at 345 kPa (50 psi) rehydrate acceptably well and their flavor is better.

The continuous explosion puffing system is a new and viable process and will yield a product that rehydrates well and has good flavor, color, and texture.